

Testing the Limits of the Single-Particle Model with $^{16}\text{O}(e, e'p)$

kevin.fissum@nuclear.lu.se
KFOTO Group



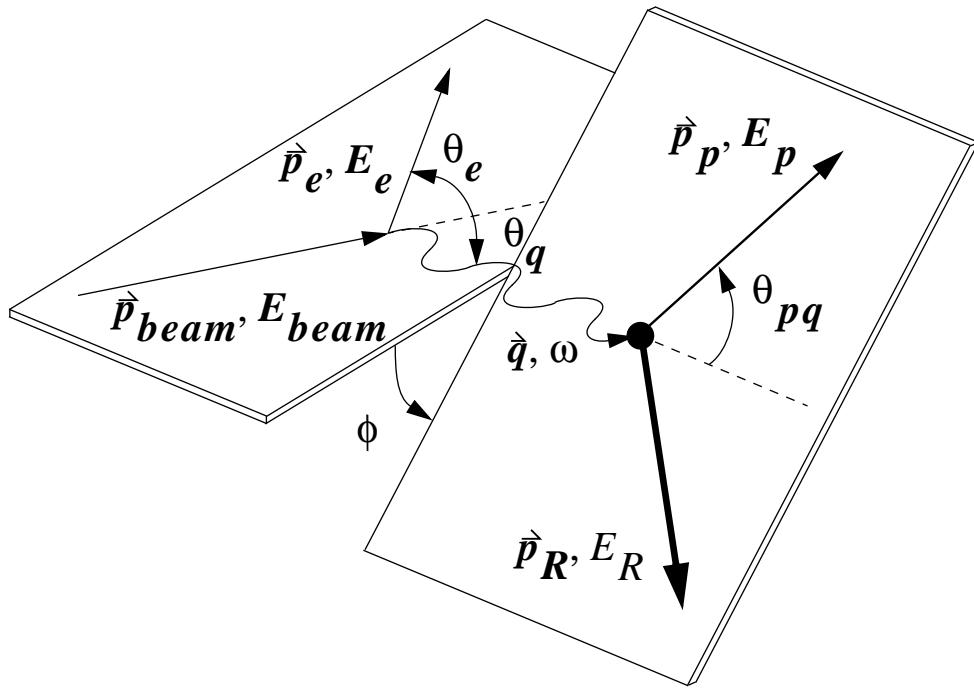
LUNDS
UNIVERSITET

SVENSKT KÄRNFYSIKERMÖTE XXII
Malmö, Sweden
November 8, 2002

This work supported in part by:
Vetenskapsrådet • Crafoordska Stiftelsen • Kungliga Fysiografiska
Sällskapet i Lund

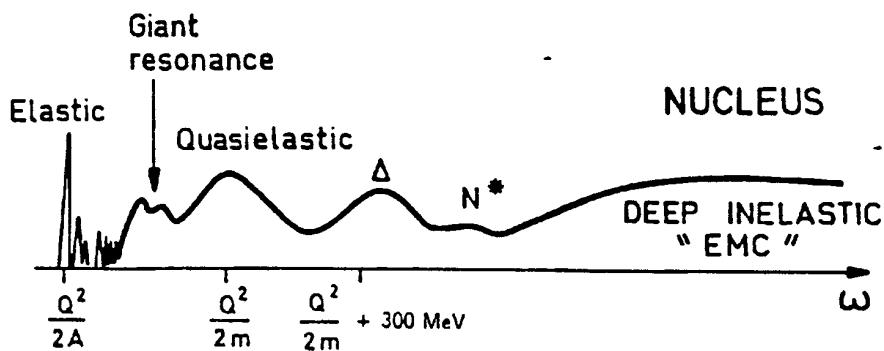
Semi-exclusive electron scattering

- for $E_e > 100$ MeV, electrons scatter from nuclei via the exchange of a single γ^* (the Born approximation)
- this γ^* illuminates the entire nuclear volume



- the scattering problem separates into two independent pieces:
 - $\langle e, e', \gamma^* \rangle$ (QED, easy)
 - $\langle \gamma^*, N, p \rangle$ (trickier...)

- $\langle \gamma^*, N, p \rangle$ may be studied by independently varying ω and \vec{q}
 - energy transfer $\omega = E_e - E'_e$ sets the nuclear excitation
 - momentum transfer $\vec{q} = \vec{k} - \vec{k}'$ sets the spatial scale
- $Q^2 = q^2 - \omega^2$ is the four-momentum transfer
- when $\omega \approx Q^2/2m_p$, a single proton in the target has absorbed the entire γ^*
 - multi-nucleon effects are minimized
 - aka “quasielastic scattering” (QE)



- the width of the QE peak is due to the distribution of bound-proton momenta

- need two more variables:

$$E_{\text{miss}} = \omega - T_p - T_{\text{recoil}}$$

- two-body breakup: (sharp) peaks at the proton separation energies

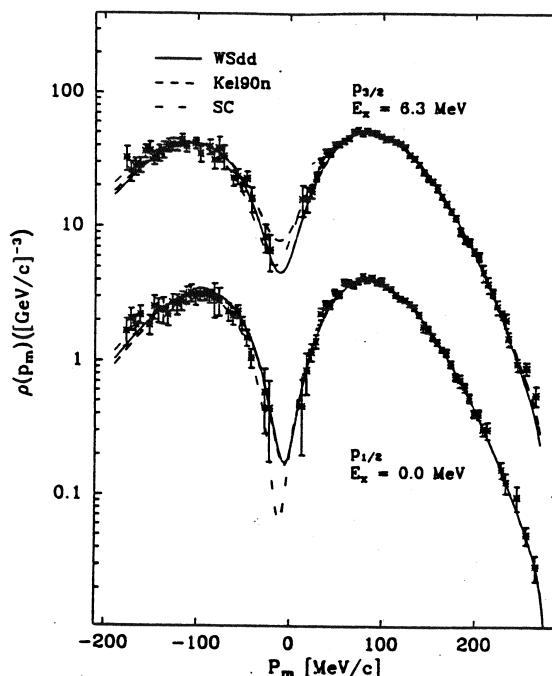
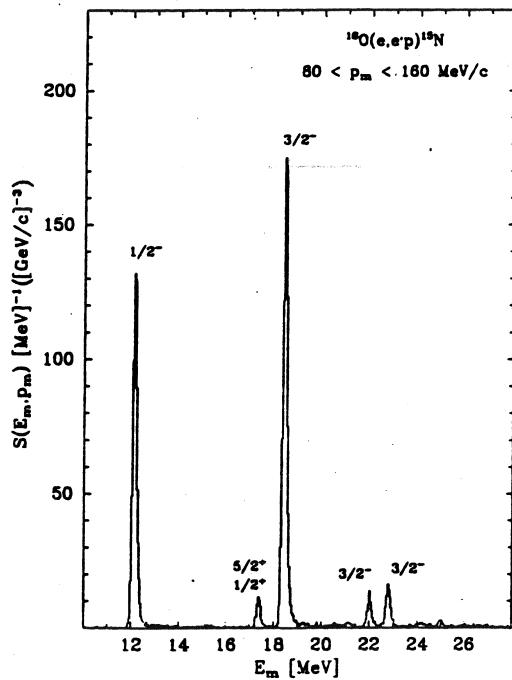
$$\vec{p}_{\text{miss}} = \vec{q} - \vec{p}_p$$

- related to the bound-proton momentum ($\ell = s,p,d,f,\dots$)

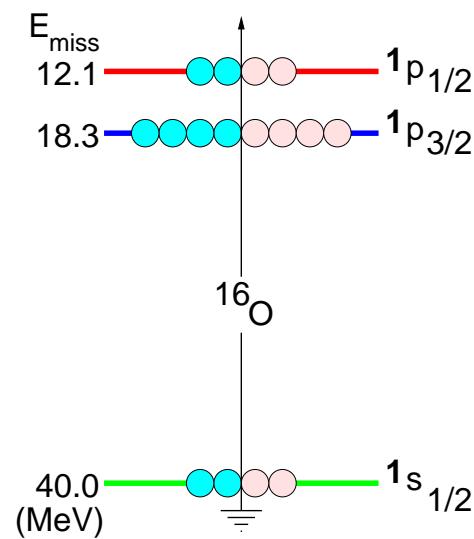
QE ($e, e' p$) yields spectra with shell-model energy levels and momentum distributions

E_{miss} (MeV)

P_{miss} (MeV/c)



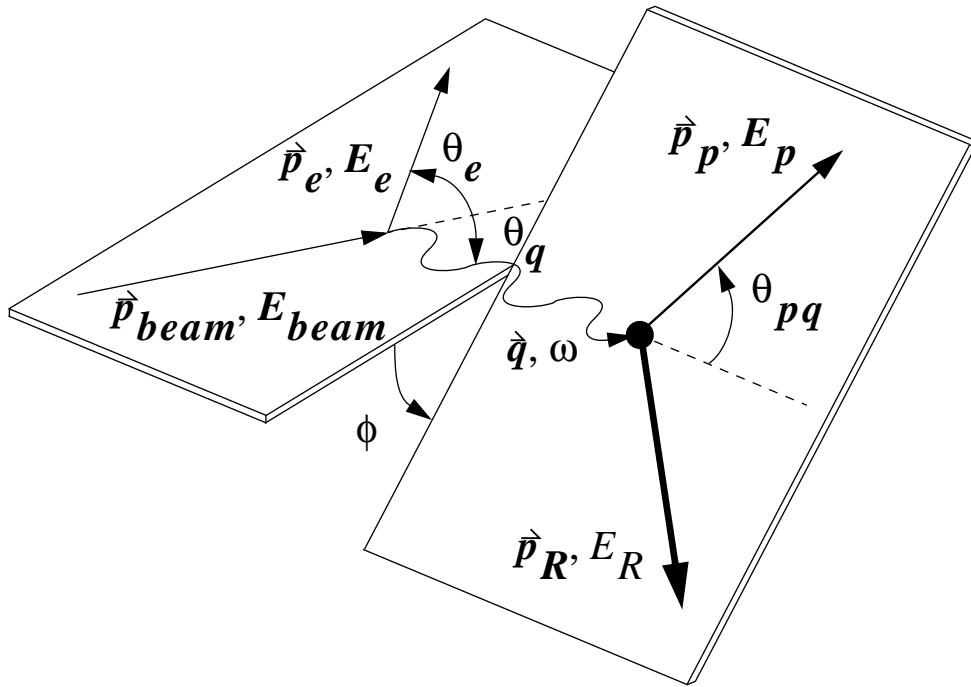
M. Leuschner et al., Phys. Rev. C. **49**, 955 (1994)



- for comprehensive reviews, see

S. Frullani and J. Mougey, Adv. Nucl. Phys. **14**, 1 (1984)
 J. J. Kelly, Adv. Nucl. Phys. **23**, 75 (1996)

$(e, e'p)$ in the Born approximation:



$$\frac{d^6\sigma}{d\Omega_e d\Omega_p dE_{\text{miss}} d\omega} = K \sigma_{\text{Mott}} [v_L \mathbf{R}_L + v_T \mathbf{R}_T + v_{LT} \mathbf{R}_{LT} \cos(\phi) + v_{TT} \mathbf{R}_{TT} \cos(2\phi)]$$

where

K = (phase space)

σ_{Mott} = (relativistic Rutherford scattering)

v = $v(q, \omega)$ (electron kinematics)

\mathbf{R} = $\mathbf{R}(q, \omega, E_{\text{miss}}, p_{\text{miss}})$ (nuclear responses)

- the response functions contain all the nuclear information

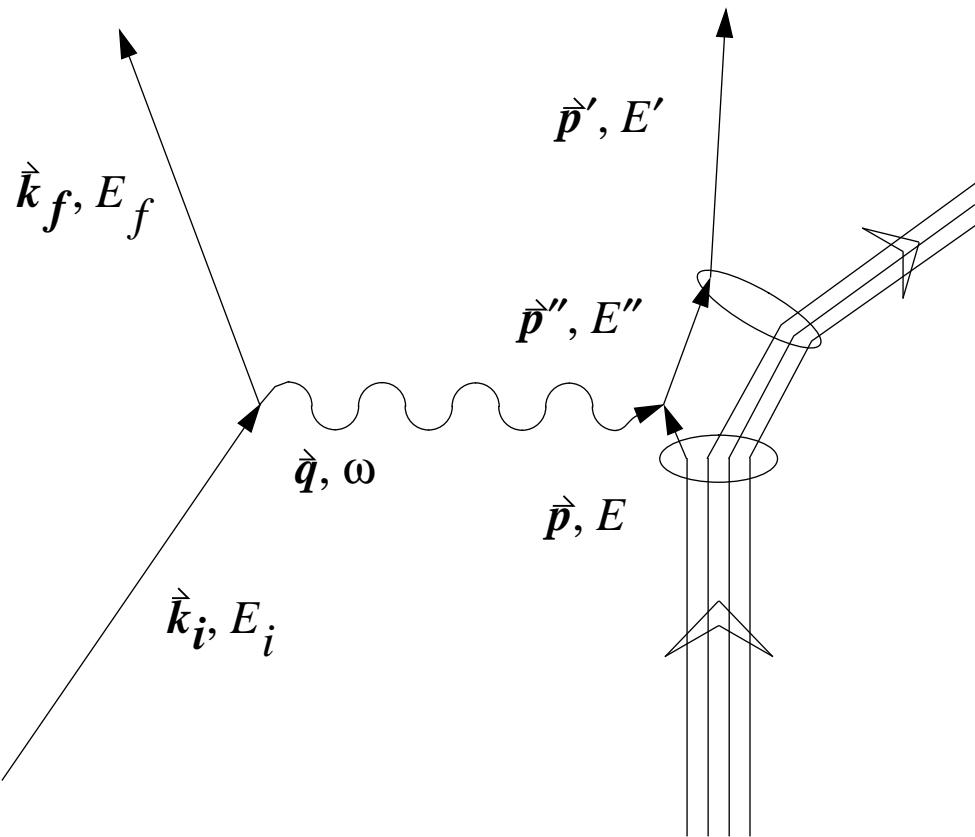
$$\begin{aligned}
 \mathbf{R}_L &= \langle \rho \rho^\dagger \rangle \\
 \mathbf{R}_T &= \langle J_{\parallel} J_{\parallel}^\dagger + J_{\perp} J_{\perp}^\dagger \rangle \\
 \mathbf{R}_{LT} \cos(\phi) &= -\langle \rho J_{\parallel}^\dagger + J_{\parallel} \rho^\dagger \rangle \\
 \mathbf{R}_{TT} \cos(2\phi) &= \langle J_{\parallel} J_{\parallel}^\dagger - J_{\perp} J_{\perp}^\dagger \rangle
 \end{aligned}$$

- multiple cross section measurements with very different kinematics allow response function extractions via a linear system of equations
- asymmetries are both particularly sensitive and particularly precise

$$\mathbf{A}_{LT} = \frac{(\mathbf{d}^6 \sigma_-) - (\mathbf{d}^6 \sigma_+)}{(\mathbf{d}^6 \sigma_-) + (\mathbf{d}^6 \sigma_+)}$$

Calculations:

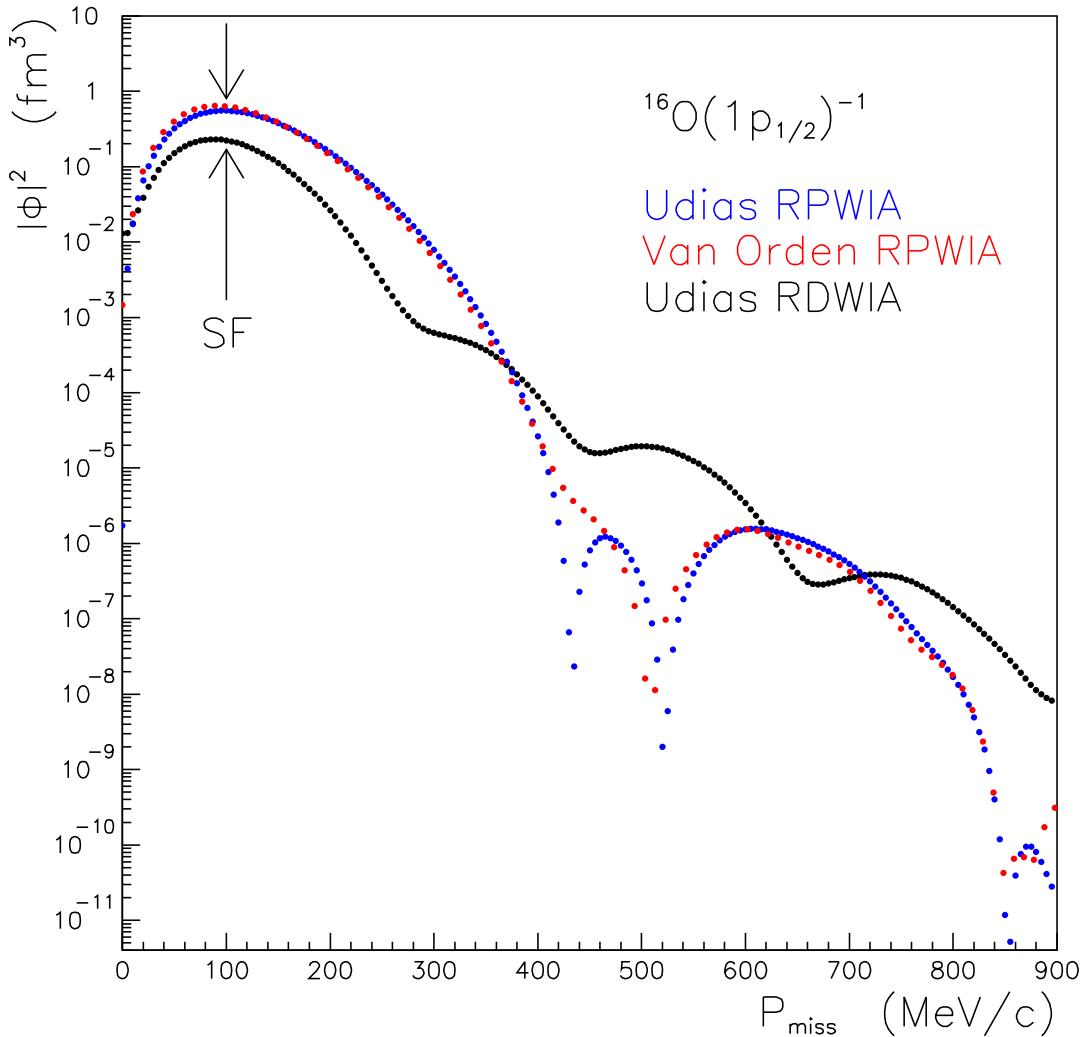
- Distorted Wave Impulse Approximation



- distortions are handled via an optical potential

E. D. Cooper et al., Phys. Rev. C **47**, 297 (1993)

- DWIA is typically **30%** below PWIA
- the ‘spectroscopic factor’ (SF) sets the overall normalization



A. Pickelsimer and J.W. Van Orden, Phys. Rev. C. **40**, 290 (1989)
J. M. Udiás et al., Phys. Rev. C. **64**, 024614 (2001)

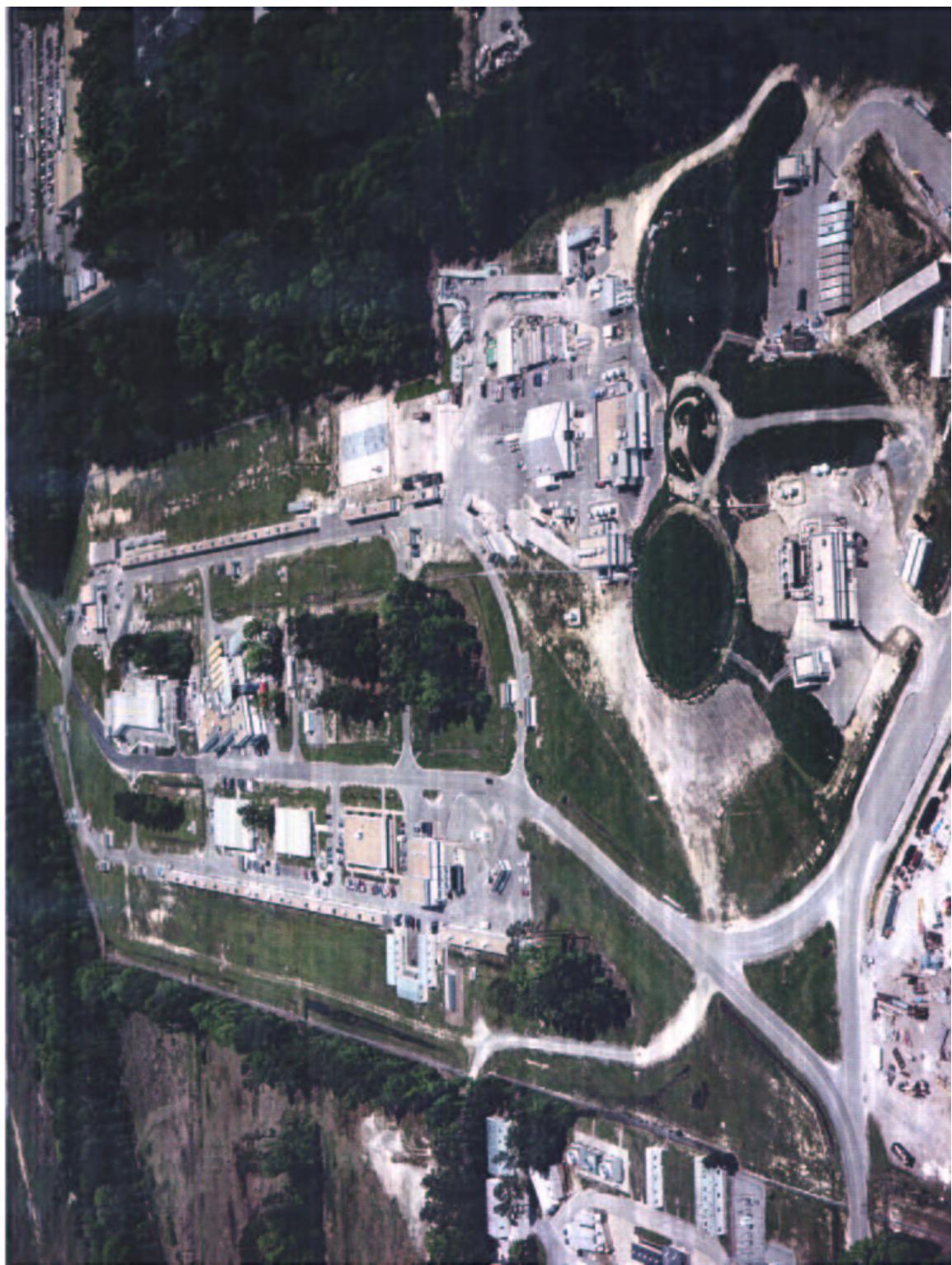


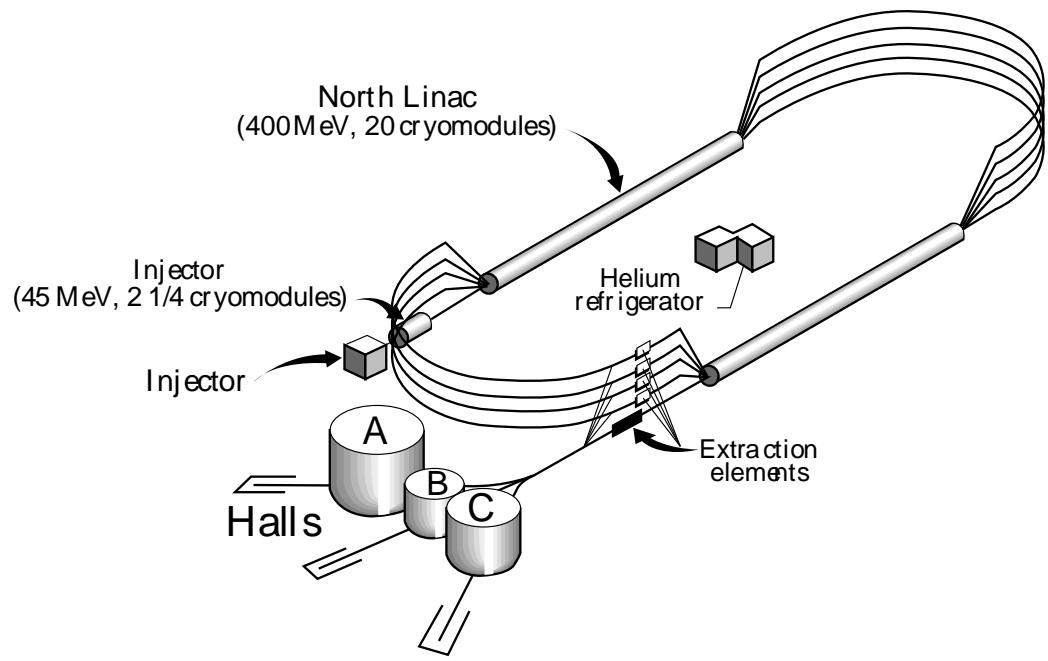
Albers Equal-Area Conic Projection

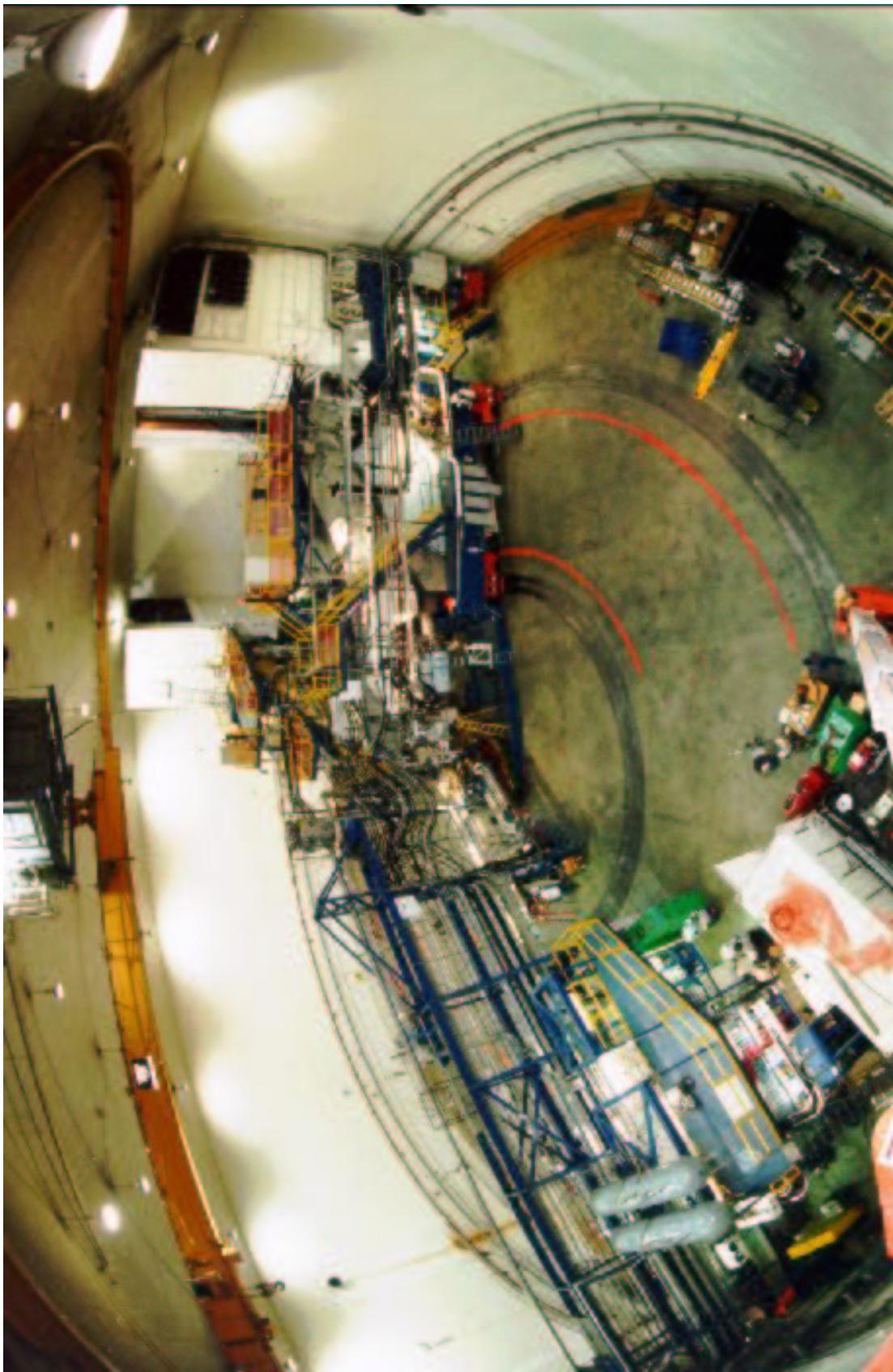
1:20000000

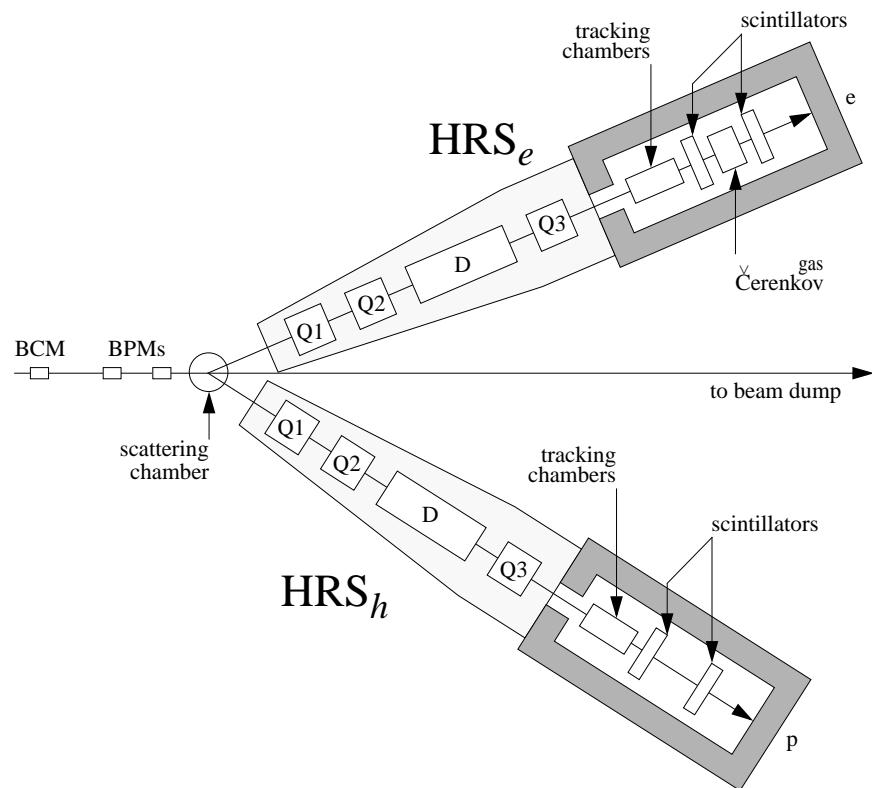
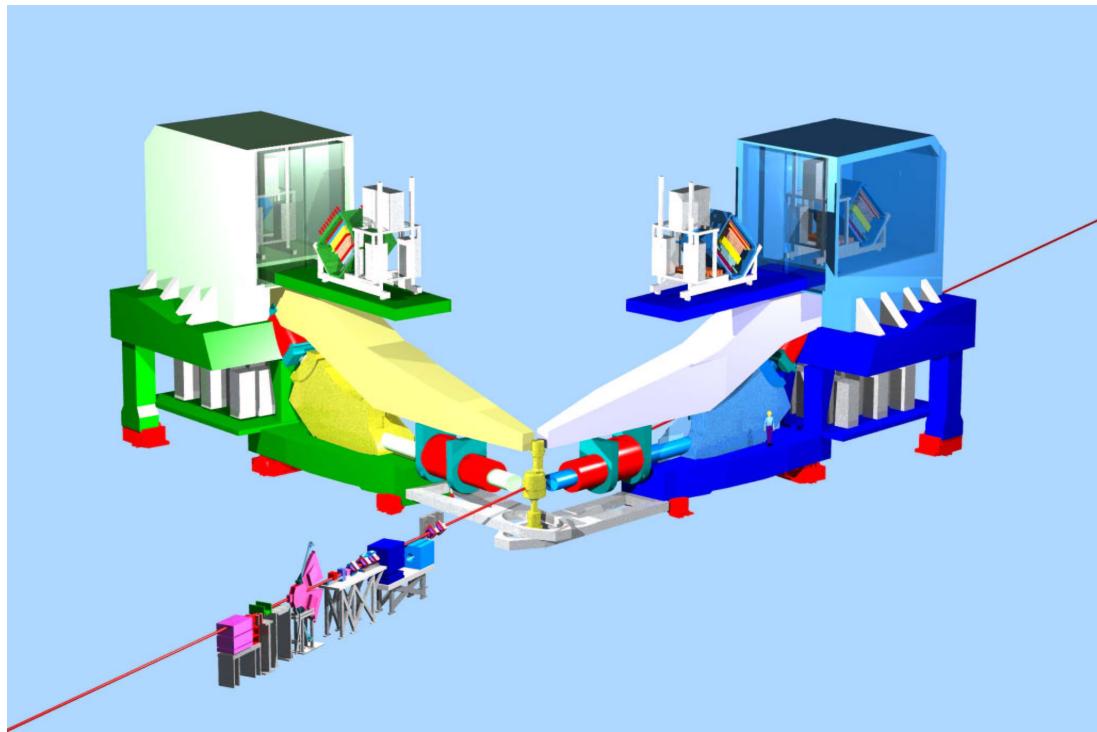
USA, 48 States

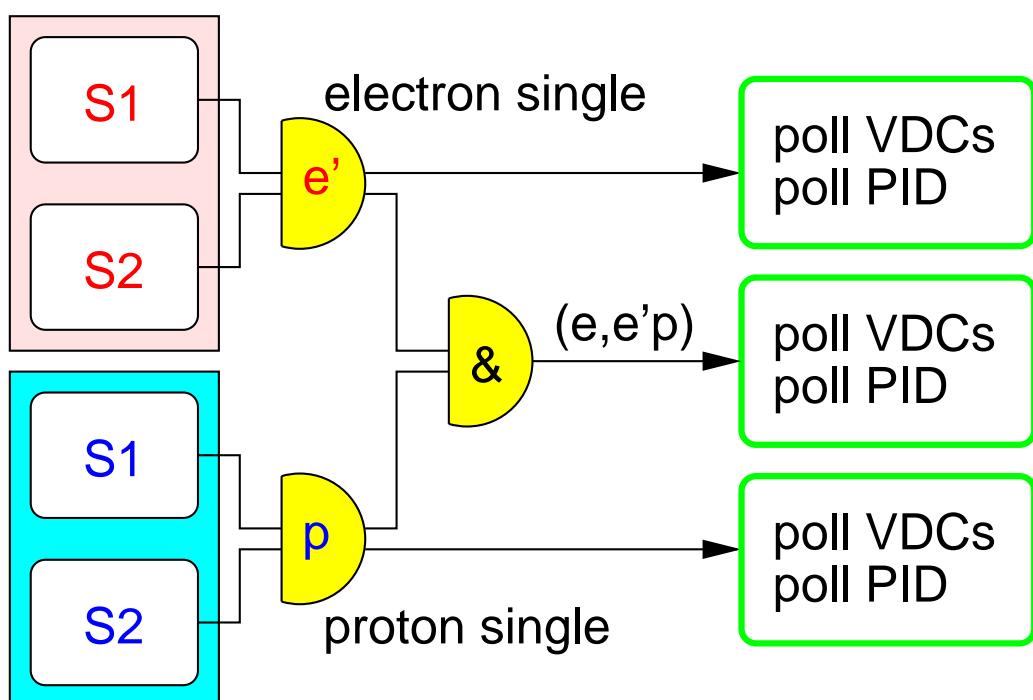
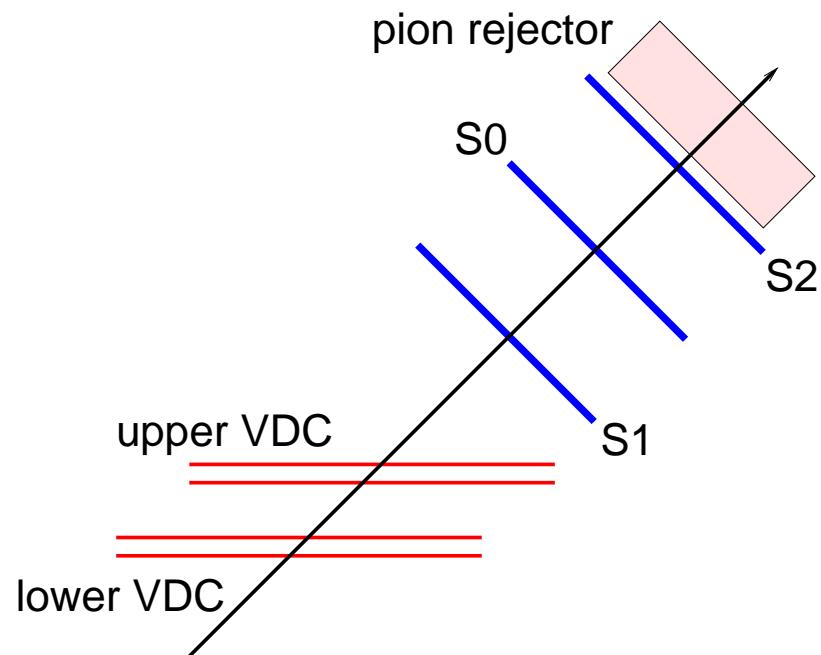


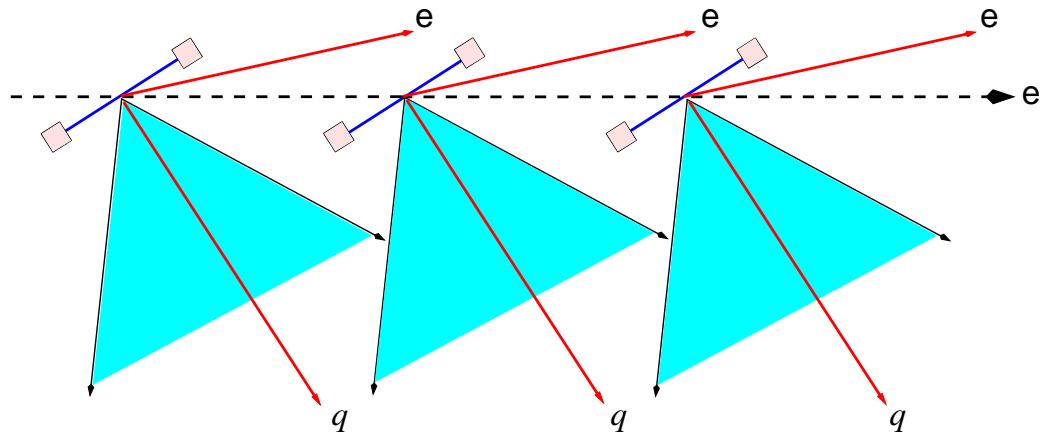




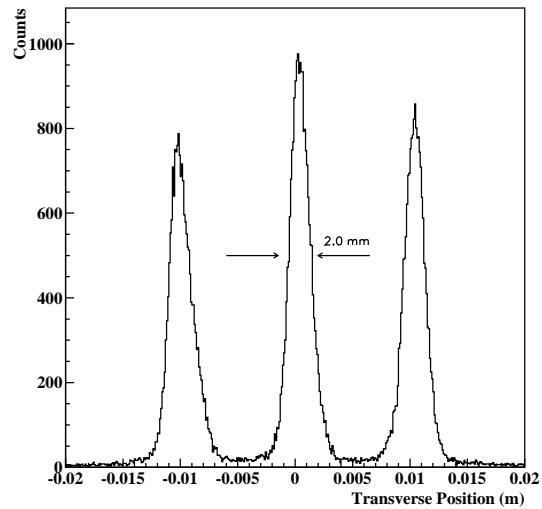
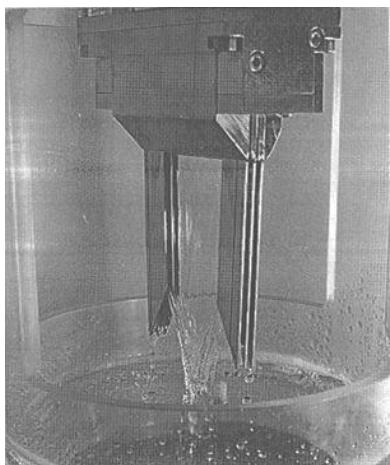








- H_2O target is self-calibrating and self-normalizing
- three foils reduce energy loss and background
- \vec{q} measured via a pinhole collimator



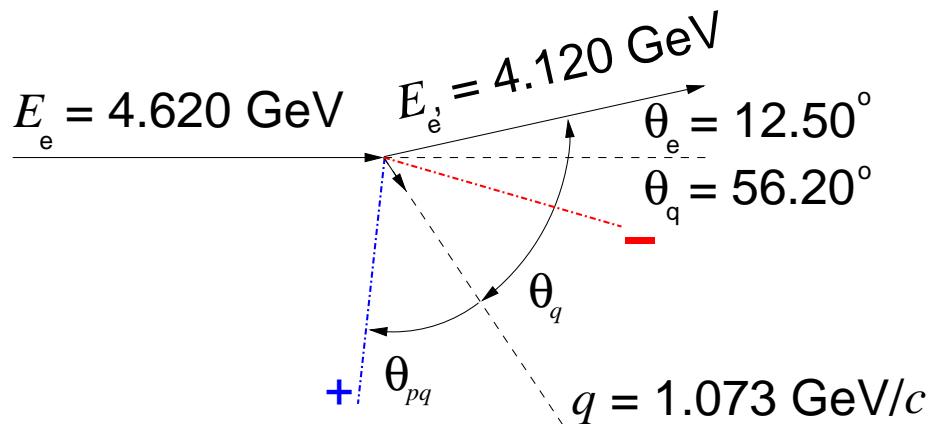
F. Garibaldi et al., NIM **A314**, 1 (1992)

$$|\vec{q}| \approx 1 \text{ GeV}/c, \omega \approx 0.5 \text{ GeV}$$

$$Q^2 \approx 0.9 (\text{GeV}/c)^2, x_B \approx 1$$

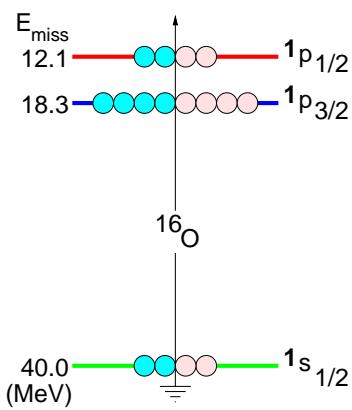
<http://www.jlab.org/~fissum/e89003.html>

<http://www.jlab.org/~fissum/e00102/e00102.html>

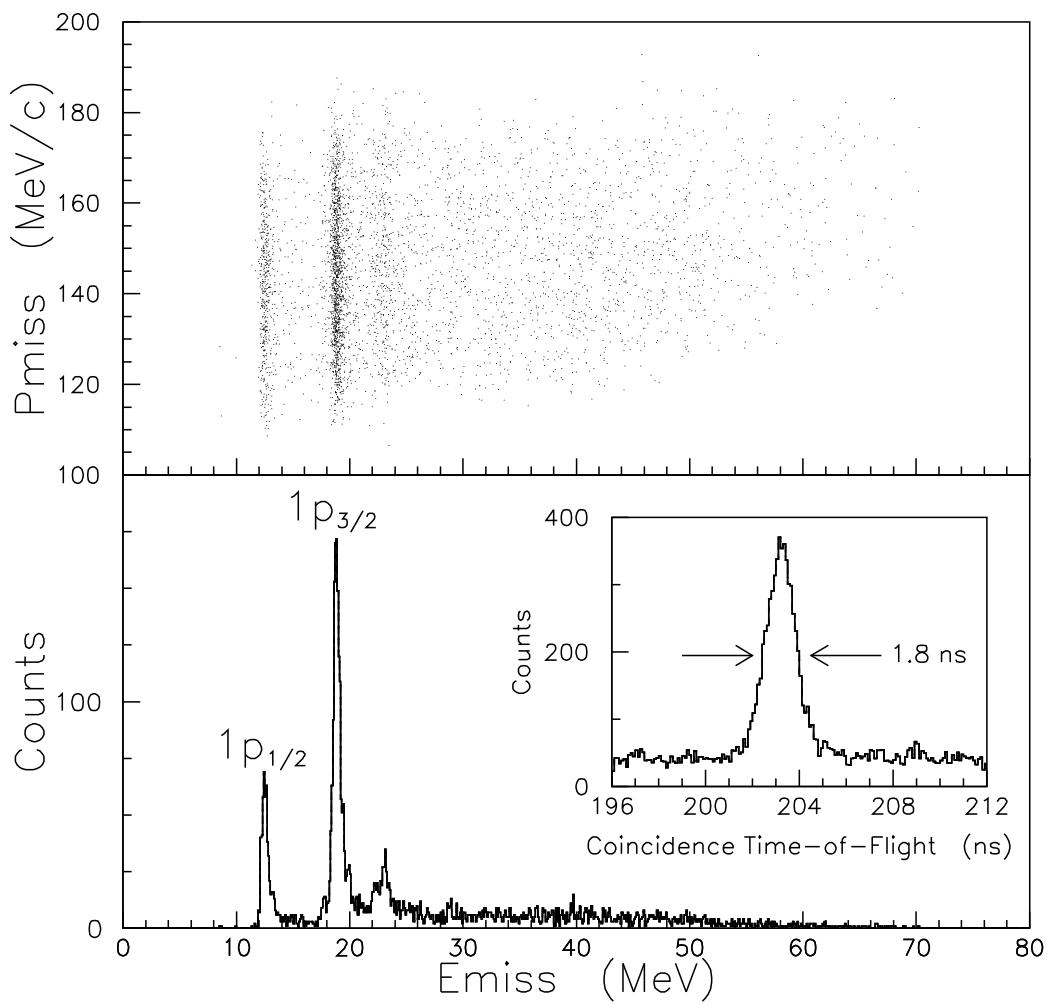


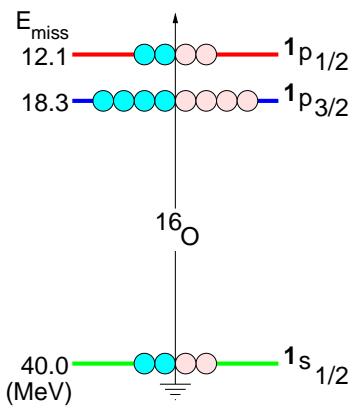
$$A_{LT} = \frac{(d^6\sigma_-) - (d^6\sigma_+)}{(d^6\sigma_-) + (d^6\sigma_+)}$$

- Ph.D. project for M. Andersson, LU
- ran October - December, 2001
- collected 8 Tb of QE data

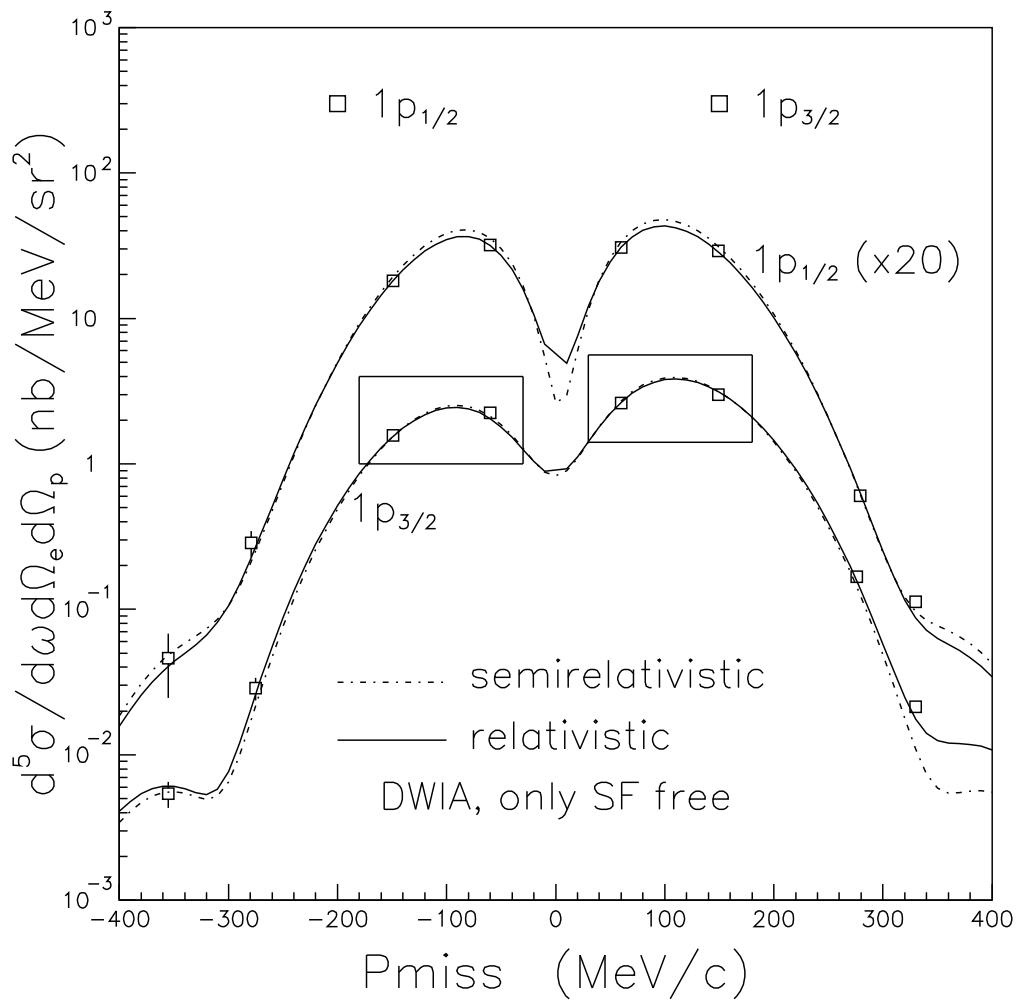


Typical data:

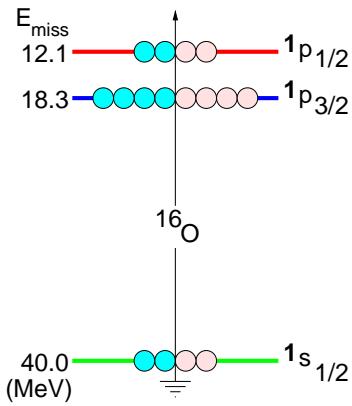




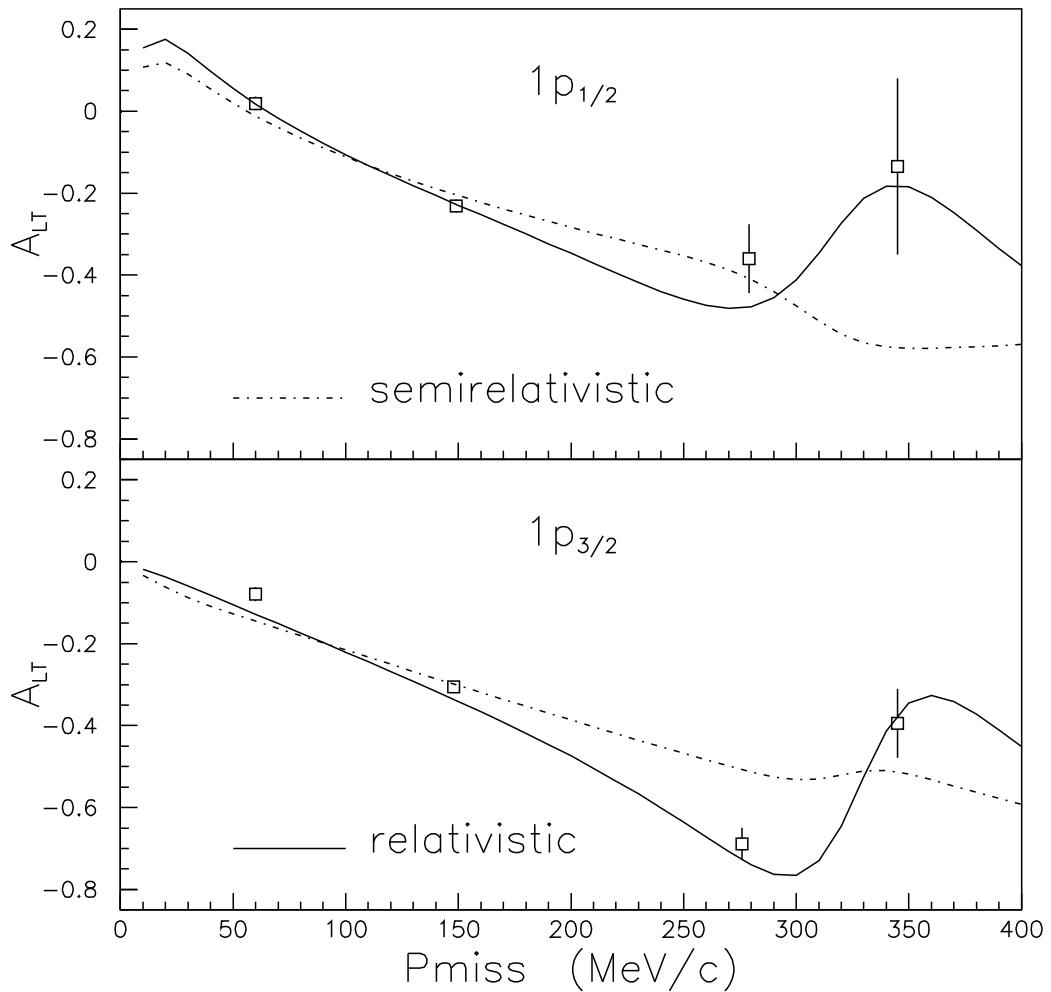
1p-shell legacy results:



- J. Gao et al., Phys. Rev. Lett. **84**, 3265 (2000)
J. M. Udías and J. R. Vignote, Phys. Rev. C. **62**, 034302 (2000)
J. J. Kelly, Phys. Rev. C. **60**, 044609 (1999)



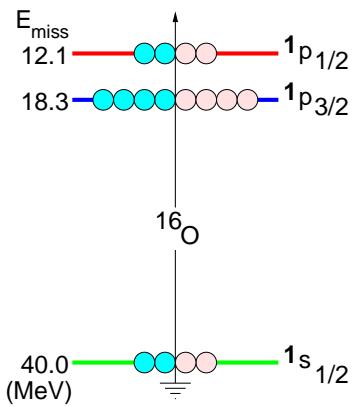
1p-shell legacy results:



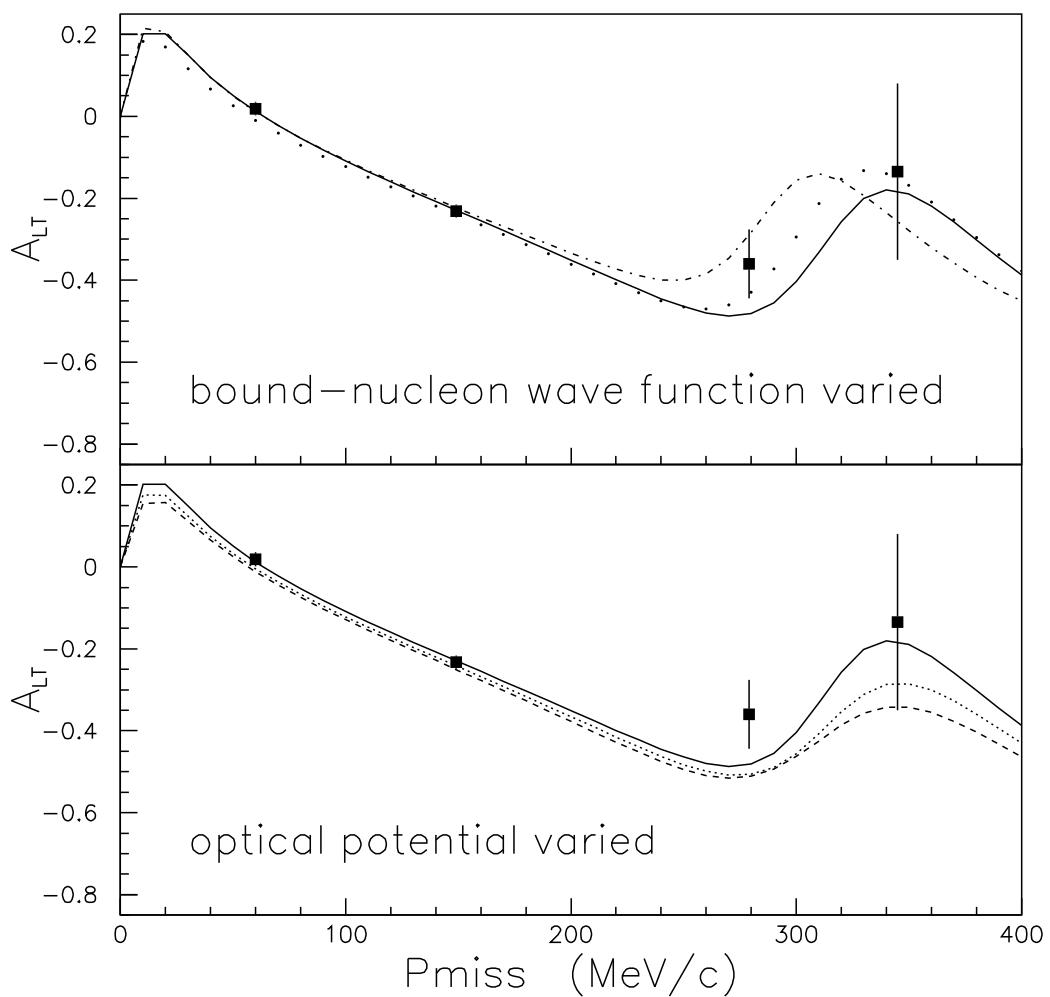
J. Gao et al., Phys. Rev. Lett. **84**, 3265 (2000)

J. M. Udías and J. R. Vignote, Phys. Rev. C. **62**, 034302 (2000)

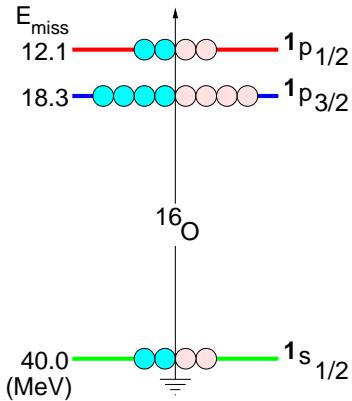
J. J. Kelly, Phys. Rev. C. **60**, 044609 (1999)



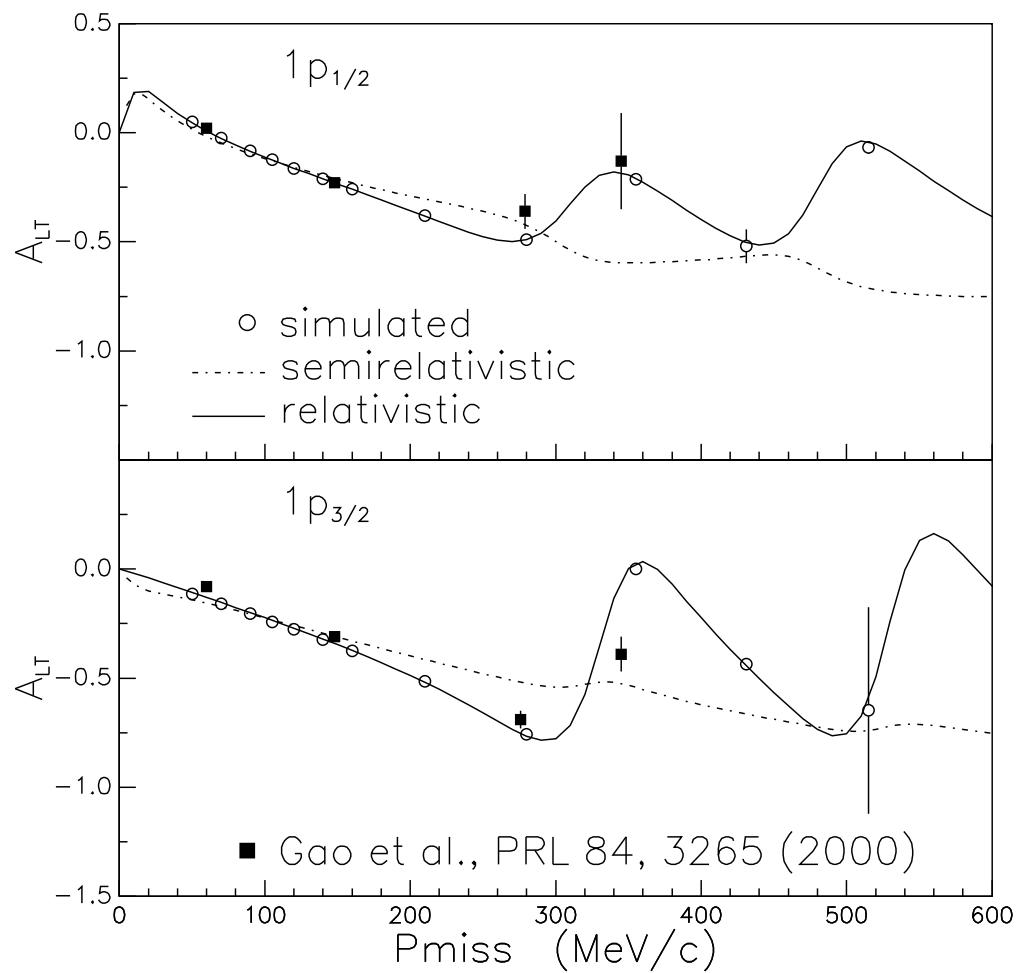
1p-shell legacy results:



- B. D. Serot and J. D. Walecka, Adv. Nucl. Phys. **16**, 1 (1986)
M. M. Sharma et al., Phys. Lett. B. **312**, 377 (1993)
J. M. Udías et al., Phys. Rev. C. **64**, 024614 (2001)
E. D. Cooper et al., Phys. Rev. C. **47**, 297 (1993)
K. G. Fissum et al., to be submitted to Phys. Rev. C.



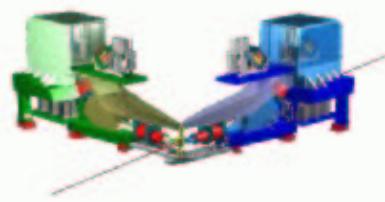
Anticipated E00-102
results:



CONCLUDING REMARKS:

- QE electron scattering is a **powerful** probe of the nuclear interior
- ^{16}O is a very **valuable** laboratory
- rDWIA does surprisingly **well** at describing QE $1p$ -shell data out to $p_{\text{miss}} \approx 300 \text{ MeV}/c$
 - **relativistic** calculations are needed to reproduce the **diffractive** structure in \mathbf{A}_{LT}
 - the choice of bound-nucleon **wave function** shifts the **location** of the structure
 - the choice of **optical potential** sets the **amplitude** of the structure

recently completed measurements for
 $0 < p_{\text{miss}} < 750 \text{ MeV}/c$
will **definitively test the limits** of our
rDWIA model



Collaboration Institutions involved in E00-102

Argonne National Laboratory, USA

California State University, USA

College of St. Mary's, Canada

College of William and Mary, USA

Florida State University, USA

INFN, Italy

ISN, France

Jefferson Lab, USA

Lund University, Sweden

Massachusetts Institute of Technology, USA

Norfolk State University, USA

North Carolina Central University, USA

Northwestern University, USA

Old Dominion University, USA

Rutgers, USA

University of Illinois, USA

University of Madrid, Spain

University of Maryland, USA

University of New Hampshire, USA

University of Virginia, USA